（別紙様式５）

変革を駆動する先端物理・数学プログラム（FoPM）
国外連携機関長期研修　報告書

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I'm currently working on special optical quantum state generation for the realization of the optical quantum computer. So far, I have been working on quantum state generation using continuous wave (CW) light, which is emitted continuously over time. However, by our research it gradually became clear that pulsed light, rather than CW light, was more suitable for generating highly pure states [1]. Therefore, I decided to work on quantum state generation using pulsed light as my PhD project. As my lab had been using CW light for 20 years and I had no experience of experiments using pulsed light, I decided to use this opportunity to gain such experience. I spent about three months in the group of Nicolas Treps at the Sorbonne University (Paris, France), who is world-renowned for quantum state generation using pulsed light. In addition, Nicolas is a friend of my supervisor Prof. Akira Furusawa for a long time.

<About daily life in the lab>
The Nicolas's group is a large group with four main experimental systems, among which I was allowed to participate in a non-classical (non-Gaussian) quantum state generation experiment using pulsed light, as I had originally hoped. The experimental group consisted of one postdoc and two PhD students, so there were four of us in the group including myself. During the first two or three weeks, many important discussions were held in French. So, I could not give meaningful opinions although I participated in the discussions. Then, at the beginning of February, I was given the opportunity to give a presentation on my research in Japan. As a result of careful preparation, including practicing my speech and preparing preliminary slides to answer possible questions, the presentation went well and was praised by many people as being very interesting. From that day, I got recognized as a group member and almost all discussions came to take place in English, and I was able to express my opinions in a meaningful way. After that, daily life in the laboratory became a lot more fun. The amount of communication with group members increased, as we all went out for sports after experiments and went out for dinner on holidays. At the end I feel that I became friends with the experimental members.

<About experimental details>
The Nicolas's group is working on experiments about non-Gaussian state generation using pulsed light and on the verification of non-Gaussianity. Non-Gaussian states are special quantum states that are known to be very important resources for quantum metrology, quantum communication and quantum computation. However, their experimental generation is difficult and currently only simple non-Gaussian states have been generated. Verification of non-Gaussianity is another challenge. As the measurement results of quantum states are stochastic in nature, it is difficult to accurately verify the properties of the generated quantum states. The goal of this research is to experimentally demonstrate a new method of non-Gaussianity verification that has been proposed theoretically in recent years [2].
During this stay, we mainly worked on building up the experimental system set-up one by one as in Fig.1. The experimental results cannot be described in detail because they include unpublished results, so here I describe some differences between experimental methods for CW light and pulsed light. For example, in optics experiments, a cavity is used to spatially confine the light for the purpose of frequency filtering, intensity enhancement, etc. When pulsed light is used, the time for the light to propagate one cycle of the cavity must precisely match the time for one cycle of the pulse. For this reason, the cavity used in the Nicolas group are equipped with an optical delay system that can adjust the cavity length, which makes alignment more difficult than when CW light is used. Also, the duration of pulsed light handled in the experiment was about several femtoseconds, which has a quite broad bandwidth when considered in terms of frequency. Therefore, it is

necessary to consider the frequency dependence of the refractive index (dispersion) when light is incident on crystals, fibers, etc. and accurate dispersion compensation is required to prevent the pulse shape from being destroyed as the light propagates. Thus a lot of experimental experiences have been gained on the problems peculiar to the use of pulsed light.

The above is a description of the daily life and experimental details during the visit. I was able to gain a variety of experiences, including communication with foreign researchers and new experimental experiences. I would like to take this opportunity to thank the staffs of my lab, Nicolas's lab, and FoPM staffs for giving me this great opportunity.

References

[1] T. Sonoyama, W. Asavanant, K. Fukui, M. Endo, J. Yoshikawa, and A. Furusawa, Analysis of optical quantum state preparation using photon detectors in the finite-temporal-resolution regime, Phys. Rev. A **105**, 043714 (2022).

[2] U. Chabaud, G. Roeland, M. Walschaers, F. Grosshans, V. Parigi, D. Markham and N. Treps, Certification of Non-Gaussian States with Operational Measurements, PRX Quantum **2**, 02033 (2021).

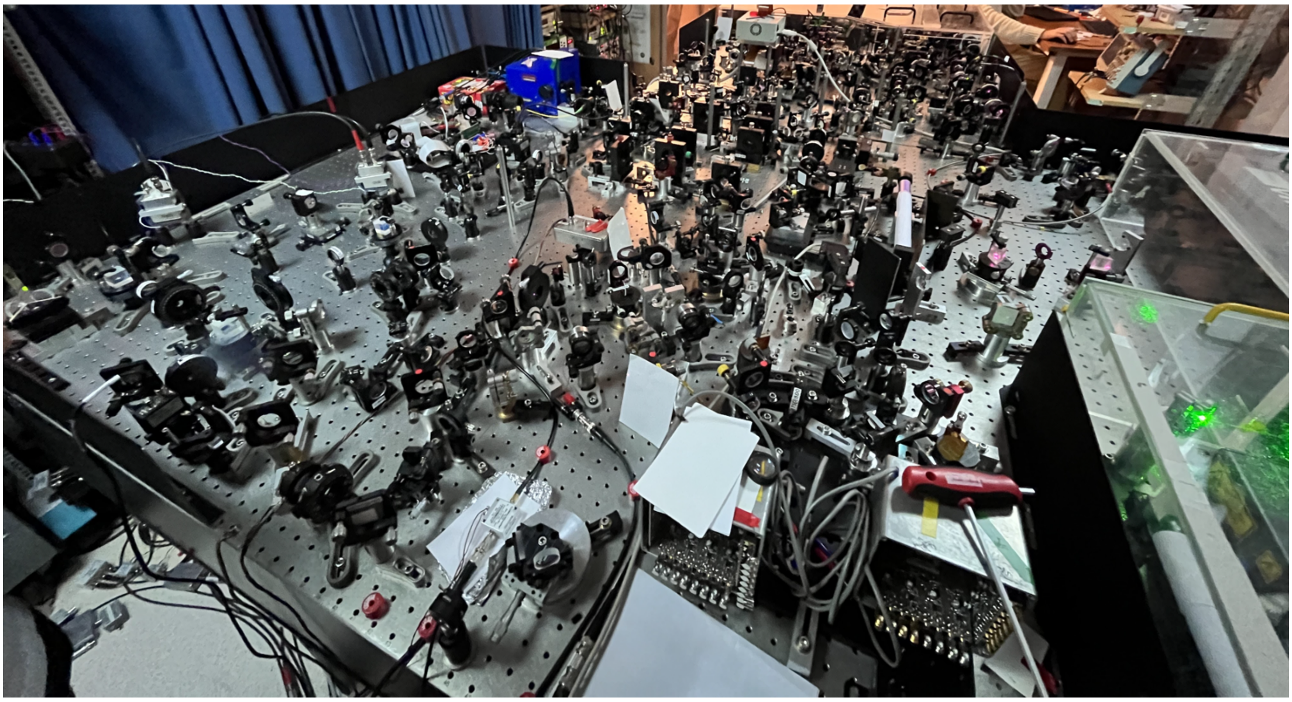

Fig 1. Experimental setup